Analyzing the Maximum Wind Power Penetration Level around Kalpitiya Peninsula

JP Karunadasa, TR Kothalawala

Abstract

This paper assesses the impact of wind integrations on the power system of Sri Lanka and analyzes the maximum wind penetration levels around Kalpitiya peninsula for the proposed years 2010, 2012, 2014 and 2016 transmission networks.

A steady state system analysis as well as a frequency and voltage stability analysis are used to figure out the wind penetration limit appropriately. Finally, a transient stability analysis is performed to confirm the stable operation of the wind integrated power systems.

The widely known power system simulation software package PSS®E is used to model wind turbines and perform steady state and stability analyses.

This research project concludes that 20MW; 90MW, 185MW and 220MW wind absorptions are feasible in the years 2010, 2012, 2014 and 2016 respectively at the Puttlam Grid substation /Power Station (GS/PS). Approximately 30% wind availability is considered for the steady state system analysis. In addition, 5% spinning reserve response on droop is assumed for the years 2010 and 2012 and 10% spinning reserve response on droop is assumed for the years 2012 and 2014.

Key Words: *Wind Power Penetration, Power system, Frequency stability, Voltage stability*

1. Introduction

The Government of Sri Lanka has declared the importance of developing renewable energy in line with the national policy of maximizing indigenous sources and ensuring fuel diversity. Sri Lanka has exploited hydropower resources to almost its maximum economical potential. Only a limited number of small and medium scale hydropower plants are yet to be developed, and these are already in various stages of development. Therefore, the country is now clearly at the cross roads as far as future generation is concerned.

Wind is one of the promising renewable energy options available for grid connected power. In addition, wind-mapping results for Sri Lanka show a very good wind potential in the Kalpitiya area.

At present a large number of wind power development proposals have been submitted to the Ceylon Electricity Board (CEB) in order to get approval to connect into the national grid. A clear idea about the power system's capability of absorbing wind power is essential when granting permission to develop such wind farms. This study is an attempt to figure out the wind absorption capability of the Sri Lankan power system around the Kalpitiya peninsula. The outcome will be a quantified wind penetration level in the Kalpitiya peninsula based on the limit at which the adverse effects of wind power start to affect the power system.

Eng. (Prof.) J.P.Karunadasa(CEng,MIE(Sri Lanka)), Head of the Department, Department of Electrical Engineering, University of Moratuwa, Eng. (Mrs.) T.R.Kothalawala (MIESL), Electrical Engineer, Transmission Projects Branch, Ceylon Electricity Board.(e-mail: karu@elect.mrt.ac.lk, thure_2003@yahoo.com)

Out of the three common wind generating technologies, the doubly fed induction generator (DIFG) technology is used to model wind turbine generators as it is the most popular technology at present.

In this study, the widely known power system simulation software package PSS®E was used. This program contains dynamic simulation models for wind turbines that have been successfully used by numerous PSS®E users around the globe.

In section 2, the system configurations and modeling approach will be discussed. Steady state system analysis including load flow, contingency and transmission transfer limits will be discussed in section 3. Section 4 will present the frequency stability analysis, while section 5 presents the voltage stability part. Section 6 will reinvestigate the transient stability of the power system with proposed wind integrations in section 4&5. In section 7 the conclusions of the research project are summarized and topics for further research are indicated.

2. Wind Modelling

Puttlam 132/33kV Grid Substation (GS) and Puttlam Power Station (PS) Switchyard were considered as the grid integration points for the wind power generated around the Kalpitiya area as they are located in the vicinity of the wind sites. This study assumed that the wind power generated at various sites around the Kalpitiya area will be taken into Puttlam GS or Puttlam PS using 33kV feeders.

This study uses GE 3.6 MW wind turbines to model wind machines. Relevant WTG data are depicted in table 1 [1].

The proposed system configuration is shown in figure 1.

A wind turbine in power flow is treated as a conventional machine. All machines were represented by a single equivalent large machine behind a single equivalent reactance during machine modeling.

Table 1: Data for GE 3.6 MW WTG model

Description	Unit	Value
Generator Rating	MVA	4
P_{max}	MW	3.6
P_{min}	MW	0.16
Q_{max}	Mvar	2.08
Q_{min}	Mvar	-1.55
Terminal voltage	V	3300
X_{source}	p.u	0.8
Unit TF rating	MVA	4
Unit TF impedance	%	7
Unit TF	X/R	7.5

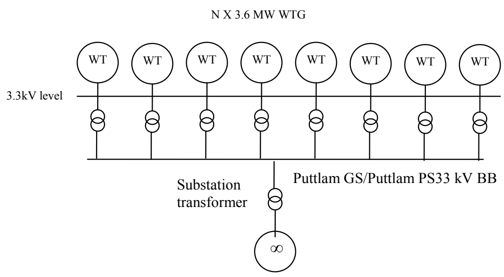

Figure 1: Proposed system configuration

3. Steady State System Analysis

The objective of the steady state system analysis is to identify several wind absorption capability levels of the proposed transmission network.

This study was performed based on year 2012, 2014 and 2016 transmission networks proposed in "Long Term Transmission Development Plan 2008-2016" , prepared by the Transmission Planning Unit of CEB .

Transmission Transfer Limit Analysis (TLTG) followed by a Load Flow Analysis was performed to identify the wind power absorption capability levels stated above.

Both normal and single contingency operating conditions were considered during the above analysis.

It was assumed that all transmission development proposals that are listed in the "Long Term Transmission Development Plan 2008-2016" would be implemented timely.

The common practice is to consider 20~30% wind resource availability for steady state analysis. Table 2 depicts the steady state wind power absorption capability at Puttlam at 132kV level without modifying the proposed network and by considering approximately 30% wind availability.

Table 2: Steady state wind power absorption capability at Puttlam 132kV level

Year	Wind Power Absorption
2010	160 MW
2012	160 MW
2014	70 MW
2016	400 MW

4. Frequency Stability Analysis

The impact of wind power on system frequency will be discussed in greater detail in this section.

Frequency stability of the power system will be investigated under sudden wind farm outages during this section. Further, the system frequency behaviour will be presented following wind resource input variations (Applied wind speed variation is shown in figure 2).

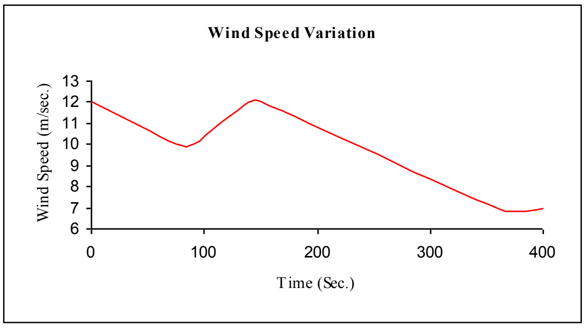

Figure 2: Applied wind speed variation

The prime mover of the wind power cannot be controlled; it impacts on the frequency control and the dispatch of the remaining conventional units in the power system. Therefore it is necessary to quantify the wind integration level where the adverse system wide frequency effects start to occur.

This study concentrated on a small geographical area located in the same wind line. Therefore, the following frequency limits were considered in order to assure a quality and reliable electricity supply to consumers and to minimize the power system operational issues

- Following total wind farm outages, the system frequency should recover without initiating load shedding schemes
- Frequency fluctuations resulting from anticipated wind speed variations should be within allowable ±1% limit.
- The maximum allowable wind ramp rate is limited to 10MW/min, as mentioned in the grid code [2].

Governor droop setting for all generators except the frequency controlling unit was set to 5% and the droop setting for frequency controlling unit was taken as 1.6% throughout this study.

Hydro generator at the Victoria power station was taken as the frequency controlling unit.

System spinning reserve (reserve available in the units with governors) was maintained approximately at 5% for the years 2010 and 2012, and about 10% spinning reserve was maintained for the years 2014 and 2016.

The system frequency impact is expected to be severe at low system load conditions. Therefore, the frequency stability analysis was carried out for the system off peak load scenario. Off peak demand considered for each year is depicted in the table below:

Table 3: System demand- off peak

Year	Off peak demand(MW)
2010	916
2012	1076
2014	1267
2016	1491

Outcome of the frequency stability analysis is summarized in table 4.

Table 4: Results of frequency stability analysis

Year	Allowable outage capacity (MW)	System frequency variation following wind variations*
2010	59	less than 1%
2012	90	less than 1%
2014	185	less than 1%
2016	220	less than 1%

*only 70% of full wind capacity was used for wind variation simulations. The applied wind speed variation is depicted in Figure 2.

5. Voltage Stability Analysis

The voltage fluctuation observed at the point of common coupling (PCC- Utility/Customer connection point) following a sudden wind farm failure and the grid short circuit level at the PCC were taken into account to determine the voltage stability limit for the network during this study.

Since there is no wind interface standard developed for Sri Lanka, the allowable maximum voltage fluctuation was limited to approximately 2% at the PCC and the obtained wind capacity was cross checked with the percentage grid short circuit level at the same point to obtain a wind integration limit at that point of the grid. The maximum voltage fluctuation at PCC was obtained by considering sudden wind farm failures.

Initially proper system configurations were identified for each study year and then the voltage stability studies were carried out for the selected configurations in order to identify the voltage stability limit (selected system configurations are depicted on figures 3-5).

Since local impact depends highly on the local loads, both night peak and off peak loading scenarios were appropriately taken into account during the voltage stability analysis.

Results of voltage stability analysis are summarized in table 5.

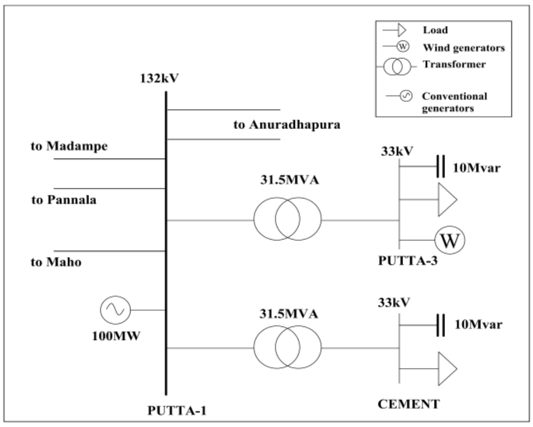

Figure 3: System configuration for wind integration at Puttlam - Year 2010

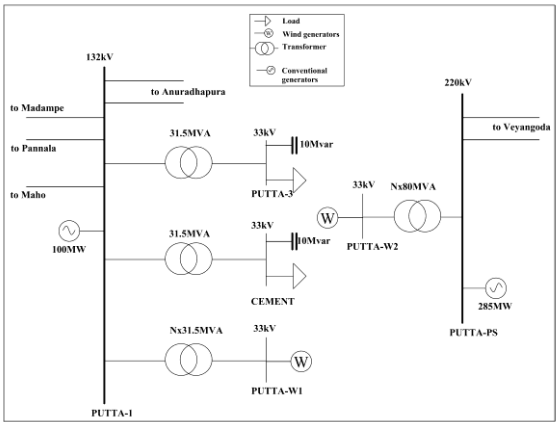

Figure 4: System configuration for wind integration at Puttlam - Year 2012

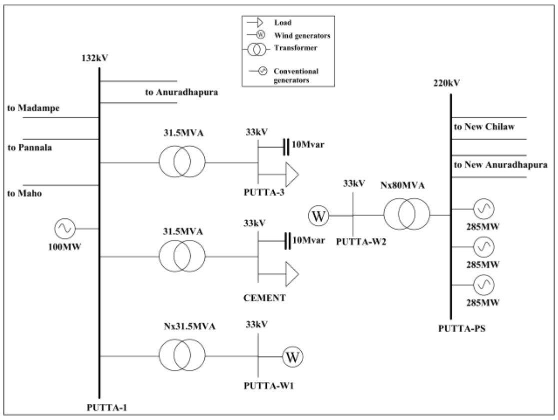

Figure 5: System configuration for wind integration at Puttlam - Year 2014 and 2016

Table 4: Results of voltage stability analysis

Year	Voltage Level	Wind Capacity (MW)	Observed maximum voltage variation (%)*	% SCC**
2010	33kV	20	2.3	7.8
2012	132kV	85	1.8	7.9
	220kV	80	1.9	5.3
2014	132kV	90	1.8	5.2
	220kV	95	2.0	2.7
2016	132kV	90	2.0	6.1
	220kV	135	2.4	3.4

*% of nominal voltage
** Short Circuit Capacity

6. Transient Stability Analysis

Transient stability analysis was carried out for wind integrated year 2012, 2014 and 2016 power systems. During the study, the transmission system was subjected to the following specific pre-identified transient system disturbances which are expected to be critical in each year.

1. Puttlam- Veyangoda 132kV line, three phase fault
2. Puttlam – New_Chilaw 220kV line , three phase fault
3. Puttlam- New Anuradhapura 220kV line , three phase fault
4. Puttlam 285MW unit tripping
5. Puttlam- Anuradhapura 132kV line, three phase fault
6. Heladanavi 100 MW unit tripping
7. Puttlam – New_Chilaw 132kV line, three phase fault
8. Tripping of all wind farms

Studies for 1, 2, 3, 5 and 7 were carried out under two switching sequences as given below

Successful Re-closing

t=0 Fault occurs
t=120ms fault cleared & circuit tripped
t=620ms circuit re-closed

Unsuccessful Re-closing

t=0 Fault occurs
t=120ms circuit tripped
t=620ms circuit re-closed with fault
t=740ms circuit tripped

It was observed that the system is stable in the transient state following critical system disturbances for all years studied following both switching sequences. Transient stability results are depicted in table 6.

Table 5: Results of transient stability analysis

Fault	Location	Scenario		
		NP	DP	OP
Transient Stability Analysis- Year 2012				
Puttlam – Veyangoda 132kV line , 3-ph fault	Puttlam end	SS	SS	SS
Puttlam 285MW unit tripping	N/A	SS	SS	SSLS
Puttlam- Anuradhapura 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Heladanavi unit tripping	N/A	SS	SS	SS
Puttlam – New_Chilaw 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Wind farm tripping	N/A	SS	SS	SS
Transient Stability Analysis- Year 2014				
Puttlam – New_Chilaw 220kV line , 3-ph fault	Puttlam end	SS	SS	SS
Puttlam- New Anuradhapura 220kV line , 3-ph fault	Puttlam end	SS	SS	SS
Puttlam 285MW unit tripping	N/A	SS	SS	SSLS
Puttlam- Anuradhapura 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Heladanavi unit tripping	N/A	SS	SS	SS
Puttlam – New_Chilaw 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Wind farm tripping	N/A	SS	SS	SS
Transient Stability Analysis- Year 2016				
Puttlam – New_Chilaw 220kV line , 3-ph fault	Puttlam end	SS	SS	SS
Puttlam- New Anuradhapura 220kV line , 3-ph fault	Puttlam end	SS	SS	SS
Puttlam 285MW unit tripping	N/A	SS	SS	SSLS
Puttlam- Anuradhapura 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Puttlam – New_Chilaw 132kV line, 3-ph fault	Puttlam end	SS	SS	SS
Wind farm tripping	N/A	SS	SS	SS

SS System Stable
SSLS System Stable with Load Shedding

7. Conclusion & Further Research Area

This research was basically focused on analyzing the impact of large wind integration on the power system both in the steady state and the transient state. Steady state, frequency stability and voltage stability studies were carried out for year 2010, 2012, 2014 and 2016 power systems to perform the above task and finally to quantify maximum wind absorption capabilities.

The outcome of this study is depicted in table 7 and the constraints applied are listed below:

- There should not be any load shedding schemes activated due to anticipated wind variations and system voltages & frequency should be recovered without any problem.

- Maintain 5% spinning reserve in year 2010 & 2012 and maintain 10% spinning reserve in year 2014 & 2016
- Maximum voltage fluctuation allowed at the Point of Common Coupling (PCC) should be limited to 2% of the nominal voltage.

Table 6: Summary of results

Year	Steady State Limit (MW)	Stability Limit (MW)	Proposed Capacity (MW)		
			33kV	132kV	220kV
2010	160	20	20	-	-
2012	160	90	-	<85	<80
2014	70	185	-	90	95
2016	400	220	-	90	130

The limits obtained from this study can be extended by applying various mitigation techniques such as introducing static var compensators and automatic generation control techniques.

In addition, wind absorption capability of the power system can be improved by maintaining higher spinning reserve levels.

However introducing mitigating techniques and maintaining a larger spinning reserve involve a considerable cost. Furthermore, intermittency of wind and varying demand in the system, along with the operation of base load (such as coal-fired generation) and must-run (such as run of river hydropower), may limit the dispatchability of wind power. Therefore, analyzing the most economical wind absorption capability level of the power system associated with a proper economic evaluation is proposed as further research to this study.

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